AN ANALYSIS OF VARIETAL CHARACTERS OF APPLES AND THEIR RELATION TO DIFFERENCES IN VARIETAL SUSCEPTIBILITY TO THE CODLING MOTH
(Cydia pomonella)

BY
DWIGHT POWELL
B.S., University of Illinois, 1933
M.S., University of Illinois, 1936

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
ENTOMOLOGY IN THE GRADUATE SCHOOL OF
THE UNIVERSITY OF ILLINOIS, 1943

URBANA, ILLINOIS
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AN ANALYSIS OF VARIETAL CHARACTERS OF APPLES AND THEIR RELATION TO DIFFERENCES IN VARIETAL SUSCEPTIBILITY TO THE CODLING MOTH (*Cydia pomonella*)

Very little work has been published on this problem. Previous workers have emphasized that certain varieties of apples have been more difficult than others to protect from codling moth infestation but no one has attempted an analysis of the characters which determine such variability among varieties.

Determinations of resistance or susceptibility in the past have been based only on results with treated fruits. The purpose of this paper is to characterize both treated and untreated fruits of different varieties and analyze the characters which tend to determine why one is more susceptible or resistant than another.

Methods and Procedure:

Winesap, Jonathan, Golden Delicious, Delicious, Grimes and Willow Twig fruits were used in this study. All varieties were not used in each test; thus, in the description of each experiment, the varieties concerned will be specified.

1. Laboratory Tests:

Untreated apples of Winesap, Jonathan and Golden Delicious were brought into the laboratory at approximately four-day intervals from June 11 to June 30, 1943. Each apple had the stem intact and was suspended by means of a stringed-tag on a horizontal stick. One newly hatched larva was placed on each apple. Four days later, each apple was examined and a record made of the place of entry, and area in which the larvae were found feeding.

Golden Delicious fruits treated in the calyx only were tested similarly and the results compared with untreated fruits of the same variety.

From August 3 to September 11, leaves of the above varieties were brought into the laboratory at three-day

intervals and newly hatched larvae allowed to feed on them. Thirty larvae were used for each variety and the test was continued until all larvae had perished. The object of this test was to determine if any difference could be discerned in the degree of palatability of the leaves of the different varieties.

2. *Field Tests on Treated and Untreated Fruit*:

Infestation counts were made on treated fruits of Golden Delicious, Winesap and Jonathan at the approximate end of the first-brood and second-brood infestations.

Two trees of each of the above named varieties were left unsprayed. These were examined June 1, 8, 22, July 1 and 22 for first-brood infestation. At least 300 apples were counted per tree on each of these dates. Twenty-five were counted in each quarter of the top-half and 50 apples per quarter of the bottom-half of each tree. The number and place of entry per apple were recorded for each date. July 22 marked the approximate end of the first-brood; thus, all infested fruits were removed from each tree and graded for number and place of entry.

Similar counts were made July 31, August 19 and September 19 on the second-brood infestation. On the latter date all apples were removed from each tree. One hundred fruits were chosen at random from the picking of each variety. The following data were taken from each apple: small and large diameter, length, degree of calyx cavity angle, depth of calyx cavity angle, stem length, degree of stem cavity angle, depth of stem cavity angle, and place or places of larval entry. (*See Plate I which illustrates these parts of the fruit.*) Stem and calyx cavity measurements were made possible by dissecting each apple through the stem and calyx ends and preserving an ink impression of the cut surface on white paper. The data were then grouped into the following categories for analysis: apples entered in the side, calyx, stem, side-calyx, side-stem, calyx-stem, side-calyx-stem and apples not entered. The remaining apples which had been removed from the trees were

graded individually for number and places of entry.

3. *Growth Studies*:

Samples of treated Winesap, Jonathan, Delicious and Golden Delicious fruits were collected May 29, June 5, 12, 18, 27, July 4, 16, 29, August 12, 21 and September 14. The number of apples constituting a sample on the various dates was as follows: May 29, 40; June 5, 25; and on each remaining date 20 apples composed one sample. Each apple was measured for small and large diameter, weight in grams, and volume, as determined by the number of cubic centimeters of water displaced.

The apples of each sample were cut into thin slices, the juice extracted by means of a tincture press, the pH determined with a Beckman pH meter, and titratable acids determined by titration with a .1018 N NaOH solution and the percent of malic acid computed.

On samples collected July 29, August 12, 21 and September 14, skin pressure tests were made by means of a Ballauf pressure tester equipped with a 3-16 inch plunger. Pressure readings were determined on all samples within three hours of the collection date at three points equidistant around the circumference of each apple.

From a sample of fifty apples of each of the above named varieties, collected August 22 and September 19, 10 fruits were selected at random, 1-8 portion removed and placed in a preservative. Later a section of peel 1 x 4 centimeters was removed with a razor blade. Five to ten lenticels per apple peel section were chosen as much at random as possible and measured. Accordingly, at least 50 lenticels were measured per variety for each sample collected.

Discussion of Results:

1. Laboratory Tests on Untreated Fruits:

Untreated apples of Winesap, Golden Delicious and Jonathan were not significantly different in susceptibility to codling moth larvae. Trends indicated that Winesap apples were more resistant, Jonathan next and Golden Delicious most susceptible. Stem entries occurred more fre-

quently in these tests than under natural environs. However, it was significant that Jonathan fruits had 52 percent stem entries as compared to Winesap and Golden Delicious with 39 and 37 percent, respectively. (*See Table* 1.)

While grading the above samples, notes were made as to the place of larval feeding after the fourth day of entry. Larvae were found in the core, seed, flesh, hypodermis and coreline but no significant differences were observed between varieties.

In comparing Golden Delicious treated and untreated in the calyx, larvae were seen to leave the poisoned calyx cup to enter the side of the fruit. Thus, the repellency of lead arsenate was apparent, indicating that the larvae preferred entry in the area with least poison. (*See Table* 2)

2. Field Observations on Untreated Fruit:

Comparing "within varietal" infestations more larvae entered the side than either calyx or stem ends on June 8. By June 22, calyx entries increased and by July 1 had surpassed in number either side or stem entrances. This increase continued through July 22.

Between varieties more first-brood calyx and stem entries occurred in Jonathan while side entries were predominant in Golden Delicious by July 22. Winesap fruits were intermediate in this respect. This same relationship was apparent during the second brood infestation. (*See Table* 3).

3. Field Observations on Treated Fruits:

On September 19, Winesap had 7.2, Jonathan 17.8 and Golden Delicious 48. percent total codling moth larval blemishes. Thus it was quite evident that, even though identical sprays were applied to each variety, the latter fruits were more susceptible, and Winesap fruits were easier to protect. (*See Table* 4)

4. Larval Longevity on Leaves:

Larvae were reared through the 3rd instar by leaf feeding. No significant difference was observed between the palatability of leaves of Jonathan, Winesap and Gold-

en Delicious. (*See Table* 5)

5. External Characters and Their Relation to Fruit Susceptibility:

a. *External Measurements*: Measurements were found significant when other factors were similar. As the skin texture of Jonathan and Winesap is similar, differences in susceptibility based on measurements were noted between these varieties. A deeper calyx cavity and sharper stem cavity were characteristic of Jonathan fruits when compared with Winesap. This was considered significant in determining a higher percentage of calyx and stem entries in Jonathan. Within varieties, apples having the sharper stem cavity had a significantly higher number of stem entries.

The longer stemmed varieties were the more susceptible. Stem length was greatest in Golden Delicious, next in Jonathan and shortest in Winesap fruits. Short-stemmed apples allow greater leaf and twig contact to the fruit, thus encouraging larvae to travel over more tree area before becoming established. As facilities of travel increase, the chances of larval survival decrease. (*See Tables* 6 & 7)

b. *Calyx-cup Development*: The larger calyx-cup encourages calyx entrances. In comparing Jonathan and Winesap the former had more calyx entries. Golden Delicious fruits had a larger calyx-cup than Jonathan but skin roughness of the former overshowed any influence a large calyx-cup might have had. (*See Plate III*)

c. *Skin Texture*: This character, as associated particularly with Golden Delicious, affected control over place of larval entry. The following varieties have been arranged by decreasing roughness of peel and decreasing susceptibility to larval attack: Golden Delicious, Grimes Golden, Delicious, Williow Twig, Jonathan and Winesap. Cuticular breaks and depressions characterized the more susceptible varieties. Winesap fruits displayed an exceedingly smooth skin. (*See Plate II*)

d. *Lenticel Size in Relation to Fruit Susceptibility*: First instar larvae have an average head width of 330

microns. Thus, it was thought that lenticels of this or greater size would encourage larval side entries. On August 22, Winesap and Jonathan fruits had an average lenticel diameter of 87 and 53 microns, respectively, with a range in Winesap of 23 to 190 and in Jonathan from 15 to 285. Golden Delicious had an average lenticel diameter of 185 microns with a range of 57 to 380. In this case, then, some lenticels exceeded 330 microns. A similar condition was found in Delicious with an average of 299 and a range of 85 to 760 microns.

On September 19, the lenticels' diameters of Winesap averaged 224, Jonathan 341, Golden Delicious 369 and Delicious 397 microns. Thus, Winesap was the only variety of the four examined with an average lenticel diameter smaller than the head width of the first-instar larvae. A definite correlation existed between susceptibility and lenticel diameter. (*See Table 8*)

e. *Skin Pressure*: Jonathan had less skin pressure than Golden Delicious and Delicious and the latter two varieties less than Winesap. Thus, no correlation could be made between skin pressure and susceptibility. (*See Table* 9)

6. Variation in Fruit Growth of Different Varieties and Its Effect on Codling Moth Control:

Of the varieties observed the smaller or slower-growing ones were more resistant to larval attack. In this study it was emphasized that the greatest daily increase of fruit size of all varieties occurred during the middle part of the season. Daily increase of surface area when plotted assumed a normal distribution curve. The period from bloom until approximately July 30 was considered the most important for codling moth protection because of this growth. The more rapid growing varieties were more vulnerable to larval infestation due to the greater decrease of residual concentration of insecticide. This was true when all varieties were given equal protection. Diameter, volume and surface area curves of Winesap and Delicious emphasize the difference in growth rate between a large and small variety (*See Graphs* 1, 2, 3)

7. Chemical Analysis:

No significant correlation was found between pH and malic acid content and varietal susceptibility. Varieties having higher sugar content, based on a soluble solids determination, were the most susceptible to larval attack. It is brought out that apples with high sugar content were possibly more attractive to larvae, thus were more highly infested. (*See Table* 10)

TABLE 1. Percent entries in untreated apples infected in the laboratory on various dates. *

GOLDEN DELICIOUS

Date	Number Larvae	Percent Entries: Side	Calyx	Stem	None	Total
June 11	98	19	52	21	8	92
June 15	47	32	34	28	6	94
June 21	57	4	41	50	5	95
June 30	29	24	24	34	18	82
TOTAL	231	17	39	37	7	93

JONATHAN

Date	Number Larvae	Percent Entries: Side	Calyx	Stem	None	Total
June 11	55	15	30	43	12	88
June 15	30	10	13	63	13	87
June 21	57	9	27	56	8	92
June 30	32	22	26	40	12	88
TOTAL	174	13	26	52	9	91

WINESAP

Date	Number Larvae	Percent Entries: Side	Calyx	Stem	None	Total
June 11	29	17	41	17	25	75
June 15	44	14	29	45	11	89
June 21	56	13	41	37	9	91
June 30	37	16	18	49	17	83
TOTAL	166	15	33	39	14	86

* Variation of ± 10 percent between varieties significant, odds 1 to 20 as determined by an analysis of variance.

TABLE 2. Comparison of Golden Delicious receiving a calyx spray and untreated when infested in the laboratory.

	*Golden Delicious	**Golden Delicious
	Calyx spray Only	Untreated
Percent Apples with Side Entries	59	17
Percent Apples with Calyx entries	15	39
Percent Apples with Stem Entries	5	37
Percent Apples Not Entered	21	7
Percent Apples Entered	79	93

*100 Apples infested—50 June 23; 50 July 2.
**231 Apples infested—98 June 11; 47 June 15; 57 June 21; and 29 June 30.

TABLE 3. Development of field codling moth infestation, on untreated apples during the season of 1942, based on number of larvae per 100 apples.

JONATHAN

Date	Side	Calyx	Stem	Total
June 1	0.	0	0	0.
June 8	3.5	0.	0.	3.5
June 22	5.0	5.6	1.0	11.6
July 1	6.0	15.5	2.0	23.5
July 22	7.4	23.8	3.6	34.8
July 31	10.0	2.3	0.	12.3
August 19	31.4	15.2	4.5	51.1
September 19	45.0	62.0	46.0	153.0

GOLDEN DELICIOUS

Date	Side	Calyx	Stem	Total
June 1	0.	0.	0.	0.
June 8	4.0	1.5	0.	5.5
June 22	9.2	6.4	0.4	16.0
July 1	16.0	18.3	1.0	35.3
July 22	12.0	26.0	2.0	40.0
July 31	9.0	3.5	0.5	13.0
August 19	41.0	22.0	2.5	65.5
September 19	63.0	50.0	14.0	127.0

WINESAP

Date	Side	Calyx	Stem	Total
June 1	0.6	0.	0.	0.
June 8	3.5	1.0	0.	4.5
June 22	9.5	9.5	0.5	19.5
July 1	13.5	27.0	2.0	42.5
July 22	9.6	21.8	1.9	33.3
July 31	9.1	4.2	0.	13.3
August 19	44.5	30.0	1.6	76.1
Septembed 19	56.0	53.0	25.0	134.0

Note: Each count was based on results of at least 300 apples per tree.

TABLE 4. Field counts of codling moth blemishes on the side of sprayed fruit, October 1, 1942.

	Winesap	Jonathan	Golden Delicious
Larvae per 100 apples entering the fruit in the side	0.2	0.8	2.0
Larvae per 100 apples stinging the fruit on the side	7.0	17.0	46.0
Larvae per 100 apples causing fruit side blemishes	7.2	17.8	48.0

Note: The above determinations are based on counts of 200 apples from each of ten sprayed trees of each variety. All trees received exactly the same codling moth spray schedule during the 1942 season. Each application was made on all trees within the same day.

TABLE 5. Larvae survival on leaves of three varieties.

	Jonathan	Winesap	Golden Delicious	
Date	No. larvae	No. larvae	No. larvae	Instar
August 3	30	30	30	1st
August 10	23	28	24	
August 13	13	23	16	
August 17	12	21	13	2nd
August 22	11	19	12	
August 25	10	16	11	
August 29	7	10	8	3rd
September 2	6	3	6	
September 5	1	2	4	
September 8	0	0	2	
September 11			0	

TABLE 6. Comparison of measurements of Jonathan, Winesap, and Golden Delicious.

	JONATHAN				WINESAP				GOLDEN DELICIOUS			
	Entries				Entries				Entries			
	side	calyx	stem	none	side	calyx	stem	none	side	calyx	stem	none
No. of Apples	47	49	35	27	42	34	26	35	55	62	11	16
Small diameter	63	62	62	62	65	64	63	64	60	61	58	64
Large diameter	67	64	65	65	67	67	66	66	63	63	61	66
Length	55	54	54	55	55	55	54	54	56	55	55	60
Degrees of stem cavity angle	43	43	40	43	47	50	47	48	41	42	38	40
Depth of stem cavity	17	17	18	17	15	15	15	16	17	17	17	17
Degrees of calyx cavity angle	41	42	43	40	39	40	40	46	41	42	37	34
Depth of calyx cavity	15	15	14	15	12	12	12	11	12	12	12	15
Stem length	20	20	20	19	16	16	16	17	28	29	30	32
Stem length beyond fruit	3	3	2	2	1	1	1	1	11	12	13	15

TABLE 7 Comparison of measurements and infestation of Winesap, Jonathan and Golden Delicious.*

	Winesap	Jonathan	Golden Delicious
Number of apples	100	100	100
Small diameter	64	63	61
Length diameter	66	66	64
Length	54	55	57
Degrees of stem cavity	47	42	40
Stem cavity depth	15	17	16
Calyx cavity angle	42	42	40
Calyx cavity depth	11	15	13
Stem length	16	20	32
Stem length beyond fruit	1	3	16
Entries in exposed side	39	28	42
Entries in unexposed side	3	19	13
Entries in calyx	34	49	62
Entries in stem	26	35	11
Apples not infested	35	27	16
Total worms	102	121	128

*All measurements are expressed in millimeters unless otherwise indicated.

TABLE 8. The average minimum, maximum, mean, and range of lenticel measurements in microns of fruit collected August 22 and September 19.*

		Lenticel measurements in microns			
		Winesap	Jonathan	Golden Delicious	Delicious
August 22	Minimum	66	47	144	257
	Maximum	109	60	231	340
	Average	87	53	185	299
	Range	23-190	15-285	57-380	85-760
September 19	Minimum	173	303	310	363
	Maximum	268	386	429	427
	Average	224	341	369	397
	Range	59-592	69-930	169-845	169-591

*Fruits collected August 22 were approximately 75 percent mature, while those collected September 19 were close to maturity.

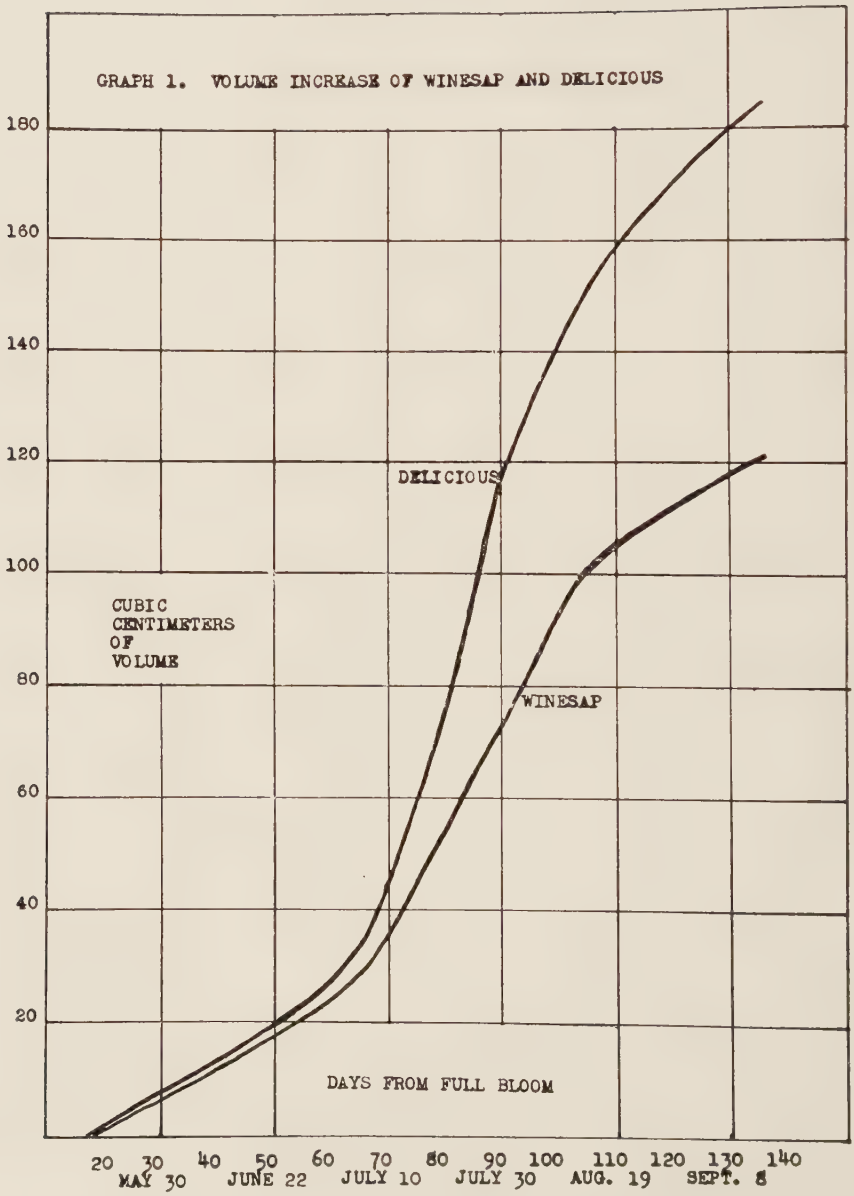
TABLE 9. Mean pounds of skin pressure of Winesap, Delicious, Jonathan, and Golden Delicious on the dates listed.*

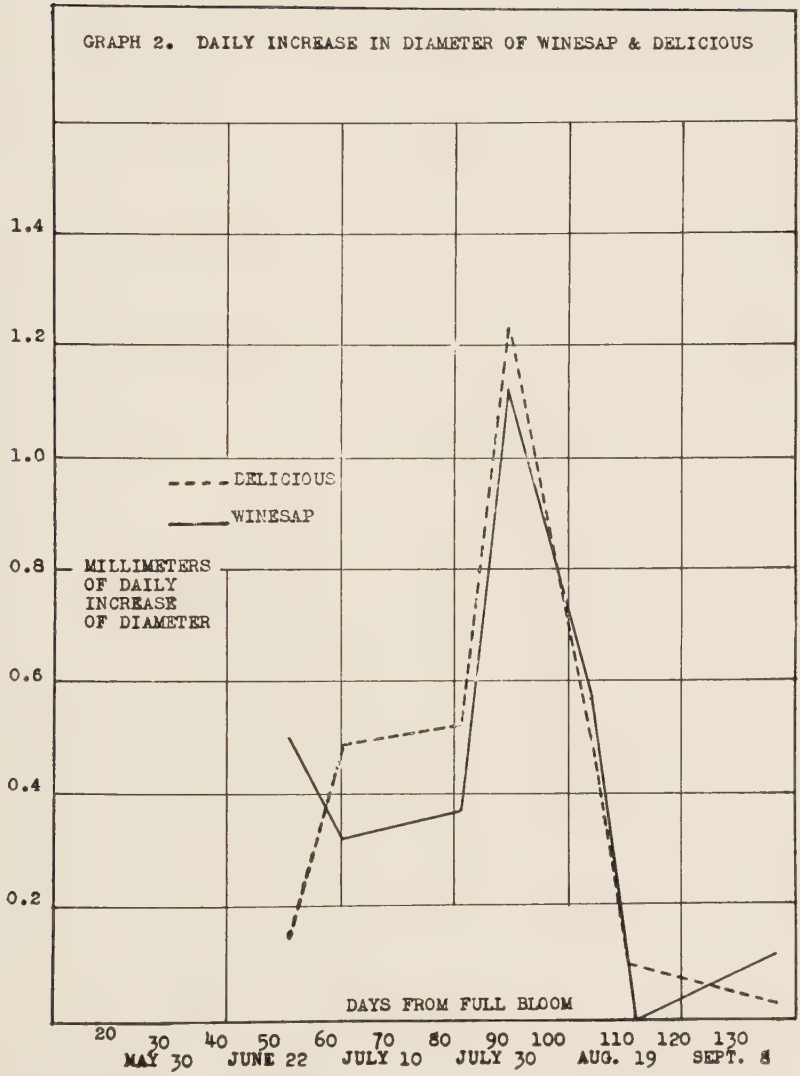
Date picked	No. apples per variety	Mean pounds of skin pressure			
		Winesap	Jonathan	Golden Delicious	Delicious
July 29	20	11.3	8.5	9.6	9.3
August 12	20	11.2	7.3	8.7	9.0
August 21	20	10.1	7.1	7.8	8.4
September 14	20	9.8	5.9	6.3	7.0

*All mean differences are highly significant (odds 1 to 30) as computed by Bessel's formula, except between Jonathan and Golden Delicious on September 14. No significance is shown between Delicious and Golden Delicious on the dates tested.

TABLE 10. pH and percent malic acid of samples collected through the summer of 1942.

Date	Delicious		Winesap		Golden Delicious		Jonathan	
	pH	acid	pH	acid	pH	acid	pH	acid
June 8	3.35	.51	3.2	1.12	3.22	.99	3.08	1.57
June 18	3.40	.50	3.25	1.11	3.21	1.02	3.09	1.43
June 27	3.38	.46	3.13	.93	3.18	.96	2.99	1.12
July 4	3.35	.33	3.25	.90	3.40	.71	3.14	1.08
July 16			3.26	.84	3.38	.64	3.13	.94
July 29	3.52	.30	3.24	.91	3.42	.57	3.16	1.04
August 12	3.70	.29	3.25	.78	3.40	.55	3.16	.96
August 21	3.76	.27	3.26	.84	3.45	.53	3.19	.95
September 15	3.92	.21	3.25	.76	3.53	.42	3.25	.64
Percent soluble solids, Sept. 15	12.1		9.9		13.3		13.1	
Percentage sugar, September 15	11.89		9.14		12.88		12.46	


GRAPH 1. VOLUME INCREASE OF WINESAP AND DELICIOUS
180
160
140
120
100
80
60
40
20
DELICIOUS
WINESAP
CUBIC CENTIMETERS OF VOLUME
DAYS FROM FULL BLOOM
20 30 40 50 60 70 80 90 100 110 120 130 140
MAY 30 JUNE 22 JULY 10 JULY 30 AUG. 19 SEPT. 8


GRAPH 2. DAILY INCREASE IN DIAMETER OF WINESAP & DELICIOUS
1.4
1.2
1.0
0.8
0.6
0.4
0.2
DELICIOUS
WINESAP
MILLIMETERS OF DAILY INCREASE OF DIAMETER
DAYS FROM FULL BLOOM
20 30 40 50 60 70 80 90 100 110 120 130
MAY 30 JUNE 22 JULY 10 JULY 30 AUG. 19 SEPT. 8

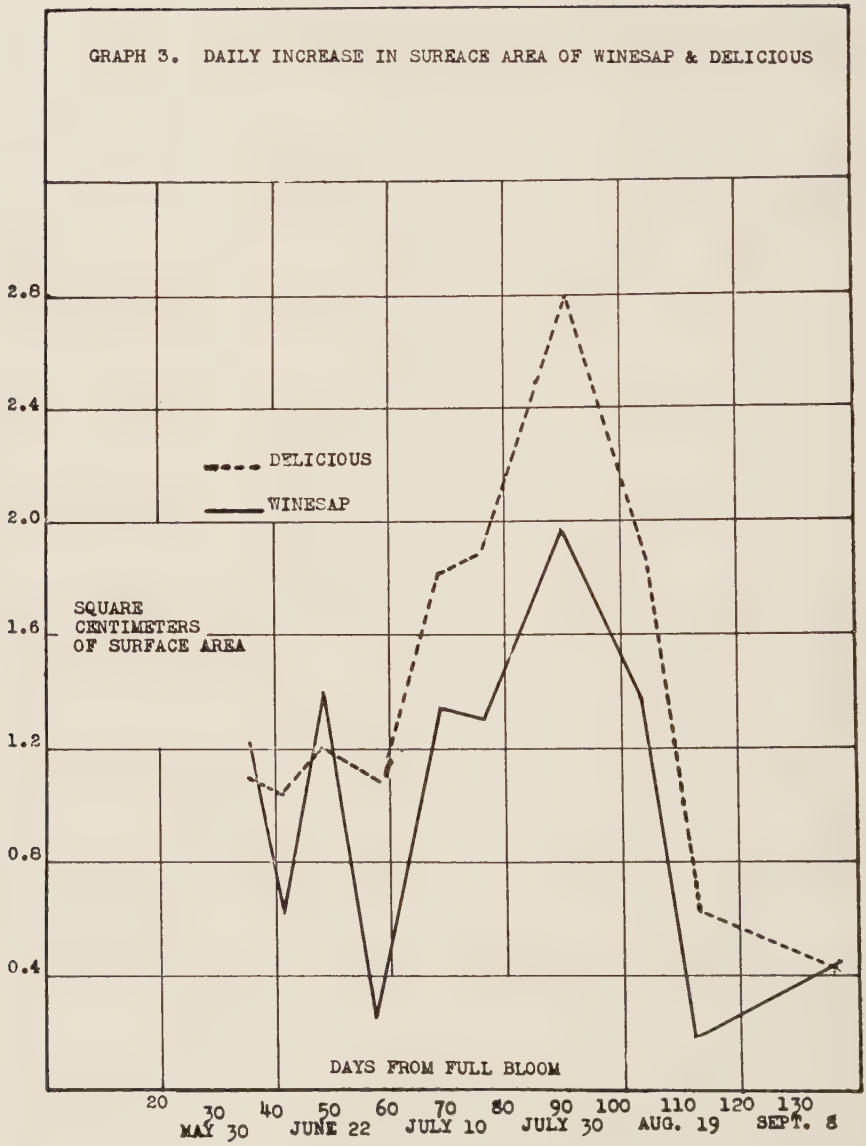

GRAPH 3. DAILY INCREASE IN SURFACE AREA OF WINESAP & DELICIOUS
2.8
2.4
2.0
1.6
1.2
0.8
0.4
DELICIOUS
WINESAP
SQUARE CENTIMETERS OF SURFACE AREA
DAYS FROM FULL BLOOM
20 30 40 50 60 70 80 90 100 110 120 130
MAY 30
JUNE 22
JULY 10
JULY 30
AUG. 19
SEPT. 8

PLATE I.

ILLUSTRATING TYPES OF FRUIT MEASUREMENTS MADE

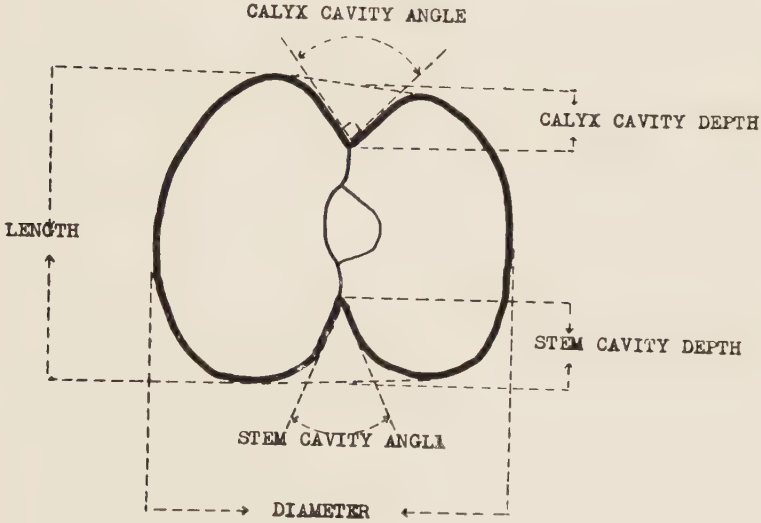


PLATE II.

SKIN STRUCTURE OF SIX VARIETIES

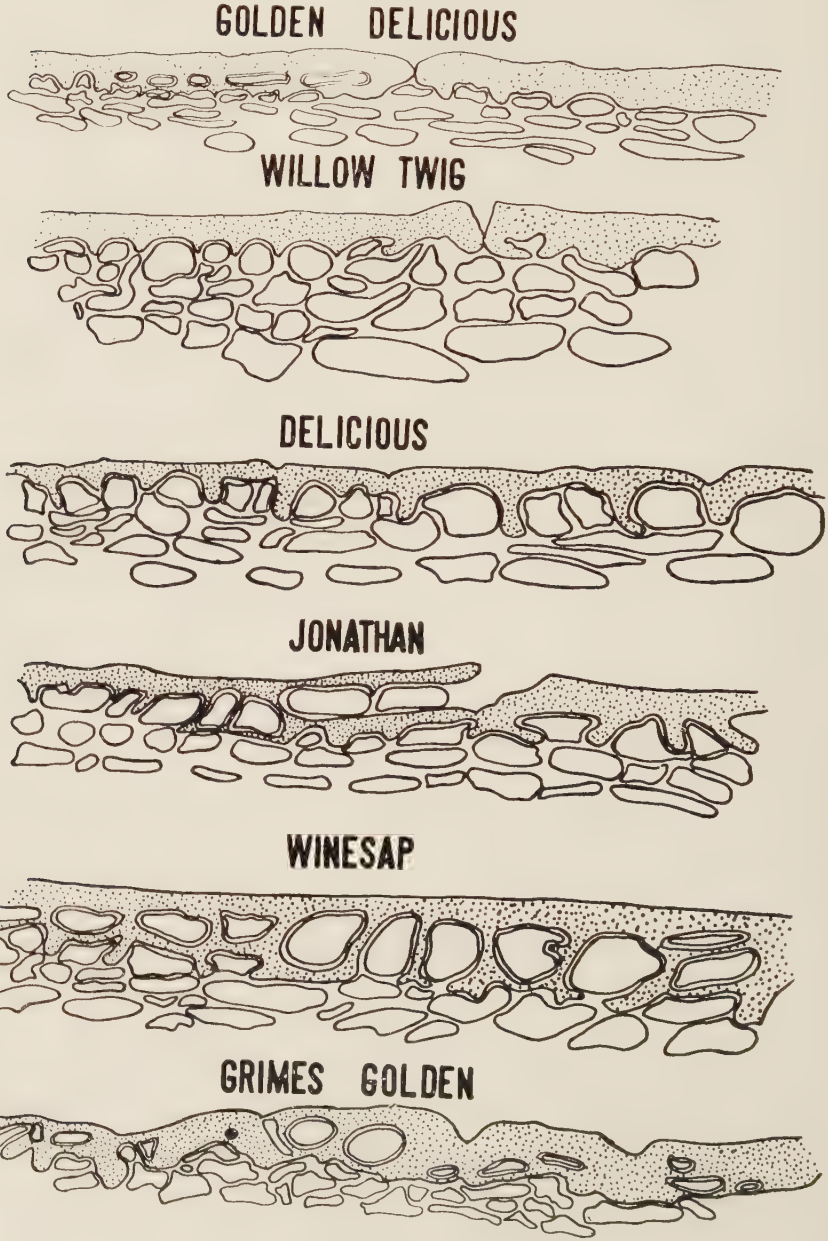
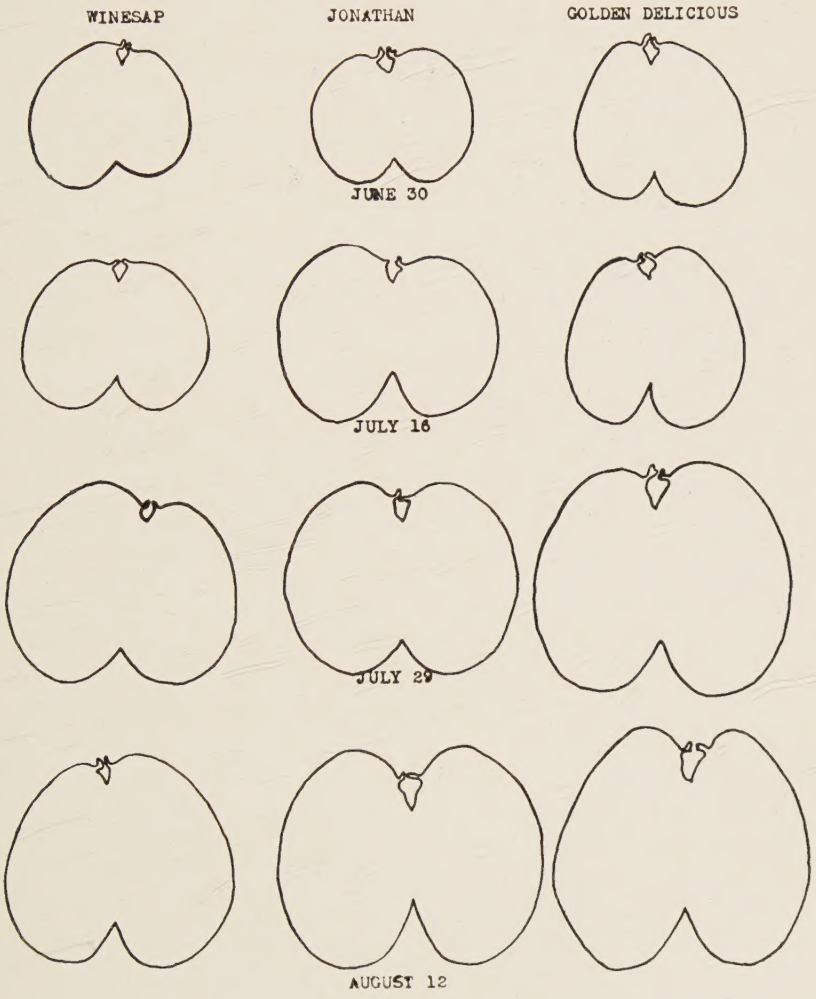


PLATE III.

COMPARATIVE SIZE OF THE CALYX-CUP OF WINESAP, JONATHAN AND GOLDEN DELICIOUS DURING THE SEASON



VITA

Dwight Powell was born October 4, 1908, at Rockton, Illinois. He attended Coon Creek grade school and Hononegah High School, both at Rockton. In 1927 he entered the University of Illinois, enrolling in the College of Education. Transfers were made to the College of Agriculture in 1928 and to the College of Liberal Arts and Science in 1929. He received a Bachelor of Arts degree in Entomology in 1933. He worked at Gardner's Grinding and Polishing Company, Beloit, Wisconsin from 1933 to 1934. In September 1934 he became part-time Assistant in Taxonomy in the Illinois State Natural History Survey and during this time pursued graduate work in Entomology at the University of Illinois. From 1935 to 1939, he was employed as Assistant Research Fellow in Economic Entomology in the Illinois State Natural History Survey and Illinois Agricultural Experiment Station. During this time he continued graduate work and received a Master of Arts degree in 1936. In 1939 he left the Survey and took a position as Associate in Plant Pathology, in the Department of Horticulture, University of Illinois. He holds this position at the present time. He married Miss Genevieve Cummings in 1935 at Roscoe, Illinois, and now has two children, Phyllis Mae, 4 years old, and Dwight Alden, 3 months old.